Mid-infrared beamline at the National Synchrotron Light Source port U2B

G.L. Carr
Research and Development Center, Grumman Aerospace and Electronics, Bethpage, New York 11714

M. Hanfland[a)]
Geophysical Laboratory, Carnegie Institution of Washington, Washington, DC 20015

G.P. Williams
National Synchrotron Light Source, Brookhaven National Laboratory, Upton, New York 11973

(Presented on 19 July 1994)

A new infrared beamline has been developed on a conventional dipole bending magnet port of the vacuum ultraviolet ring at the National Synchrotron Light Source (NSLS). The port provides approximately 12 mrad horizontal and 8 mrad vertical aperture, which limits the useful spectral range to wavelengths less than 20 μm. Though the total flux across the mid-infrared is less than that from a globar source, the calculated brightness is at least two orders of magnitude greater. Also, the synchrotron source delivers light in sub-nanosecond pulses. The developing experimental programs include studies of hydrogen and other materials at extremely high pressures, and time resolved studies of infrared sensor materials. The measurement results presented here, characterizing the actual brightness advantage and spectroscopic performance, demonstrate the synchrotron's remarkable advantage for microspectroscopic studies. © *American Institute of Physics.*

I. INTRODUCTION

Research using infrared radiation from synchrotron sources has seen steady growth over the past few years[1]. Dedicated beamlines have been constructed at the National Synchrotron Light Source (NSLS) (USA), Daresbury (UK), Lund (Sweden), UVSOR (Japan), and LURE (France). New infrared beamlines are being planned or considered for the ALS (USA), SRRC (Taiwan) and CAMD (USA). Most were built for wavelengths out to several hundred microns, where the synchrotron's brightness[2] is several orders of magnitude greater than for a globar; the standard midinfrared source. Extracting such long wavelength infrared, while maintaining the high source brightness, requires a large exit aperture from the electron beam chamber. Retrofitting existing chambers can be costly, and the required space does not always exist.

The U4IR beamline at the NSLS is one of the most active infrared facilities[1,3]. Requests for experimental access had increased to the point that a second beamline was necessary. However, not all the measurements required long wavelength performance. Mid-infrared studies of hydrogen at high pressures, semiconductor materials, and other small specimens, could make use of the high brightness or pulsed structure of infrared synchrotron radiation (SR) from a conventional bending magnet port. Table I shows the calculated properties of this source and the comparison with a globar (T~1200 K blackbody) source. Therefore, a decision was made to construct a mid-infrared beamline on such a port of the NSLS vacuum ultraviolet (VUV) ring.

II. DESIGN AND CONSTRUCTION

The purpose of the beamline is to provide mid-infrared radiation substantially superior to that from a blackbody source. An ambitious experimental program dictated that the beamline be brought to operational status quickly. Therefore, we adapted an existing port, designated U2B, on the NSLS VUV ring, and used "off-the-shelf" components whenever possible. This also minimized costs.

A schematic of the infrared extraction system is shown in Fig. 1. The vacuum chamber for the mirror optics was assembled from conventional ultrahigh vacuum (UHV) fittings and components with only minor modifications. Externally adjustable gimbal mounts support two of the three mirrors, with the remaining mirror adjusted by tilting the entire assembly on its mount. A 60 ℓ/s pump proved adequate for achieving the required vacuum of 2×10^{-9} Torr

TABLE I. Characteristics of the U2B infrared beamline at the NSLS, and brightness comparison to a $T \approx 1200$K "globar" source. An asterisk denotes a diffraction limited value, due to the 8 mrad (vert.) and 12 mrad (hor.) aperture into the storage ring.

Frequency (cm^{-1})	Source size *v* x *h* (cm)	Flux (photons/s/1%bw)	U2 brightness (photons/cm^2/sr)	globar brightness (photons/s/cm^2/sr)	U2/globar
10 000	0.03 x 0.1	8.8×10^{13}	1.6×10^{20}	1.7×10^{14}	9.5×10^{5}
1 000	0.12* x 0.1	1.9×10^{13}	9.5×10^{18}	1.2×10^{16}	7.9×10^{2}
100	1.2* x 0.8*	3.7×10^{12}	3.7×10^{16}	2.2×10^{14}	1.7×10^{2}

[a)]Present address: ESRF, Grenoble, France.

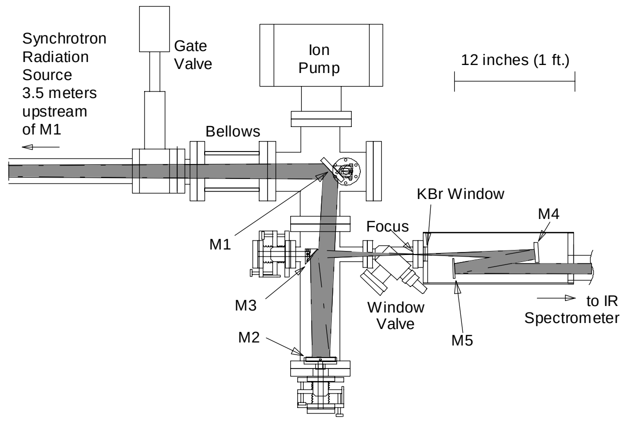

FIG. 1. Beamline extraction optics and vacuum hardware. The SR (shaded areas) enters from the left and exits to the right. Not all the hardware is shown.

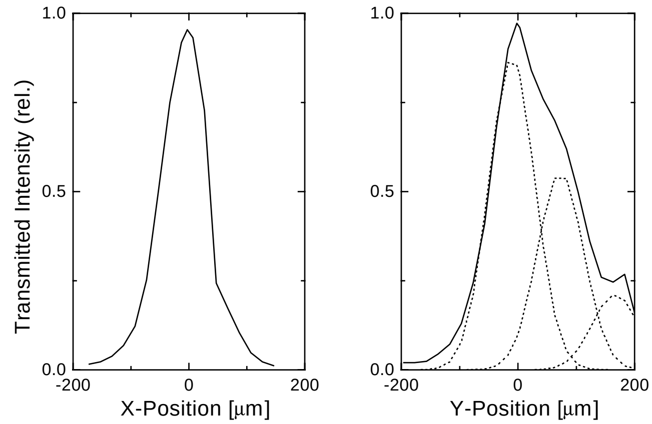

FIG. 2. Intensity profile of the infrared SR measured with a 50 μm aperture at the *f* /3.5 sample location. The vertical profile (right-hand panel) is shown deconvolved into three separate 100 μm-wide spots.

or less. Upstream of the extraction system is a standard beamline front-end, which includes photon and radiation safety shutters, and isolation valves.

UHV conditions are not needed for transporting infrared radiation, so the first three mirrors (M1-M3) serve to extract the infrared portion of the beam and bring it out from the storage ring vacuum through a window. All three mirror blanks were obtained from "stock". The mirrors were coated with silver to provide high reflectivity across the entire infrared and into the near-UV. The first mirror (M1) absorbs the large UV and X-ray SR flux, and must dissipate the associated heat. The mirror blank is made of solid oxygen-free, high conductivity (OFHC) copper, clamped to a high current UHV feedthrough (also OFHC copper) which enabled external cooling of the entire assembly.

Mirrors M2 and M3 are made from glass. M2 is an *f* /6 sphere with a 45.7 cm (18") focal length. The angle of incidence is about 3°. This leads to a small, but acceptable, amount of spherical aberration and coma. M3 reflects the beam through an all-metal valve and out from vacuum through a potassium bromide (KBr) window. This window transmits wavelengths from 200 nm to beyond 20 μm, so that in addition to infrared, experiments requiring visible or even near-UV can be performed. The beam is narrow near the focus between M3 and M4, allowing a small diameter (and therefore inexpensive) valve and window to be used. From here the beam is transported in dry nitrogen at atmospheric pressure. Mirror M4 is an *f* /6, 30.5 cm sphere which collimates the beam while M5 steers it to the entrance of an IR spectrometer located a few meters downstream. The arrangement of M4 tends to cancel some of the aberration introduced by M2. Mirrors M4 and M5 have a conventional aluminum coating, rather than silver which would degrade from occasional exposure to air. The infrared beam exits below the level of the electron beam orbit, simplifying the placement of shielding against the bremstrahlung radiation that might occur from an unexpected venting of the ring.

The image size produced at the sample location can be estimated by noting that M2 collects light from the 1 mm (horizontal) by 0.5 mm (vertical) sized source at about *f* /90, so the *f* /3.5 sample optics should demagnify by a factor of 25, yielding a 40 μm diameter spot. Ray tracing through the optical arrangement indicates that a point source will be imaged by the *f* /3.5 spectrometer sample optics into a spot 50-100 μm in diameter, due to the mirror aberrations described above. Therefore, the combination of source size and mirror aberrations are expected to produce an image about 100 μm in diameter.

III. PERFORMANCE MEASUREMENTS

Measurements at the U4IR beamline of the NSLS-VUV ring have already demonstrated the utility of subnanosecond infrared SR pulses[4]. Therefore, we have focused our performance measurements on the available brightness required for microspectroscopy or small aperture (diamond anvil cell) throughput. We have conducted a series of measurements comparing the flux throughput and signal-to-noise (S/N) of the synchrotron source with the standard spectrometer mid-infrared (globar) source for various apertures ranging from 1000 μm (1 mm) down to 50 μm.

The spectrometer is a commercial Fourier transform infrared (FTIR) instrument[5] with Ge:KBr beamsplitter and $Hg_{1-x}Cd_xTe$ (MCT) detector. This covers the beamline's primary spectral range from about 2 μm out to 15 μm. We used the spectrometer's internal globar source, which operates at a temperature of about 1200K, as the standard for comparing the SR source. The globar/MCT combination yields the best performance commercially available for the spectral range around 10 μm.

The *f* /3.5 image for the SR source was mapped, transverse to the optic axis, by measuring the transmitted signal level through a 50 mm aperture mounted on an x-y stage. The results are shown in Fig. 2. The full width at half-maximum (FWHM) in the horizontal plane is about 100 μm, consistent with the aberration and source size effects described earlier. The vertical profile is asymmetric, probably due to multiple reflections from the wedged beamsplitter of the FTIR spectrometer. The profile deconvolves into three separate spots of about 100 μm FWHM each.

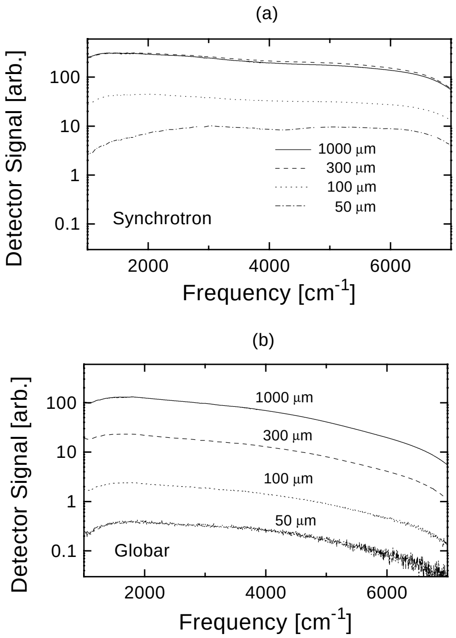

FIG. 3. Detector signal for both IR sources, measured through various dimater apertures from 50 to 1000 mm. Upper panel, synchrotron source; lower panel, globar source.

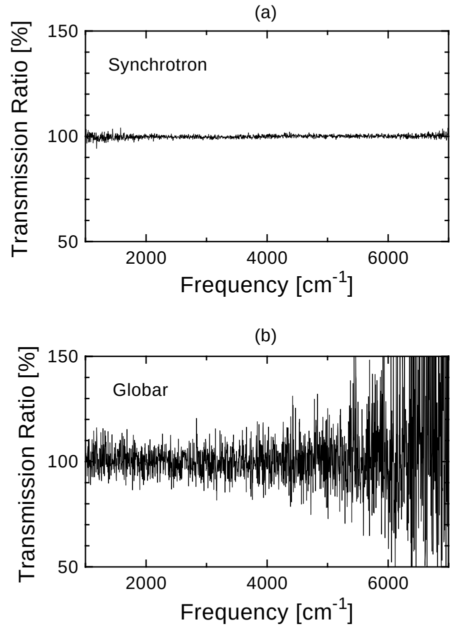

FIG. 4. 100% lines for both IR sources through the 50 µm aperture, indicating the available S/N.

We measured the signal level (proportional to the transmitted flux) through the four apertures, both for the globar and SR source. The SR output depends linearly on the stored electron beam current, and we have normalized all the SR data to a beam current of 1 A, which represents the maximum amount presently stored in the machine. During the 5 hour period between "fills", the beam decays to about 250 ma. The signal for the globar source is seen to decrease quickly (approximately as the diameter squared, as expected) as the aperture size is reduced (see Fig. 3). For the SR source, there is virtually no decrease in signal until an aperture of 100 µm is reached, and it delivers a signal throughput 10-100 times that of the globar for the 50 µm aperture.

The increased signal throughput does not necessarily lead to improved spectroscopy performance if, e.g., the synchrotron's electron orbit fluctuated in position. To check this, we have measured the run-to-run S/N for both sources. This is easily illustrated by comparing the ratios of two identical measurements, which should yield a smooth, flat line at unity (i.e. 100% lines). In Fig. 4 we show 100% lines for the 50 µm aperture. It is readily apparent that the S/N for the synchrotron source is 1 to 2 orders of magnitude better than for the globar.

IV. SUMMARY AND CONCLUSIONS

We have designed, constructed and utilized a mid-infrared beamline on a conventional bending magnet port of the NSLS-VUV ring. Design and construction were completed in a 6 month period and at modest cost. Performance measurements demonstrate that the synchrotron has substantial advantages over the conventional mid-infrared source for microspectroscopy. The available brightness is about 100 times that of a globar, limited primarily by mirror aberrations. Custom mirror optics could gain an additional factor of 10 in brightness.

The research program at U2B is well underway, and results for hydrogen at GPa pressures were recently published[6]. The high brightness and broad spectral coverage are unmatched for microspectroscopic studies, and the sub-nanosecond pulses are uniquely suited for studying dynamics in semiconductor materials. The simplicity and low cost of such mid-infrared beamlines should promote their development at other high current electron synchrotron facilities.

ACKNOWLEDGMENTS

This project was supported by the NSF (Carnegie Institution of Washington), IR&D funds (Grumman), and the DOE through contract DE-AC02-CH00016 (NSLS, BNL). We are grateful to the BNL staff who participated on this project: R. DiNardo (mirror coatings), D. Carlson (chamber installation), C.J. Hirschmugl (data manipulation), and K.M. Thorpe (infrared measurements).

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